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Simulation of the partial load operation of an urban groundwater well field

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Abstract

Our study points on a small groundwater well field of Arad City (Romania). We built in EPANET a model of the Mandruloc groundwater well field (13 wells). Due to the metering of the consumers, the demand dropped, so the well field is working at partial loads. We simulated the operation of the well field, by stopping 3 and 6 successive wells, placed at different positions. To avoid the wells overcharge, calculations were performed assuming that pumps run at variable speed. The proposed pumping algorithm gives better results with respect to a previous solution with orifice plates.

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Keywords: Groundwater well field; partial load; variable speed driven pumps; orifice plates; EPANET

1. Introduction

Arad City – the county seat and principal city of Arad County is located in Western Romania; it is a medium-sized city with about 159000 inhabitants. The water supply system of the city is based on 3 Water Treatment Plants (WTP). The biggest WTP can receive a total flow rate of about 2500 l/s, from two groundwater well fields: one, called Arad-Nord, with 92 wells and a smaller one, called Mandruloc, with 13 wells.

The present paper focuses on the Mandruloc groundwater well field. The total design flow rate for all 13 wells is about 226 l/s. Water is pumped through submersible centrifugal pumps; each vertical discharge pipe has 150mm

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diameter and 30m length. The vertical discharge pipes are interconnected through pipes with diameters ranging between 200mm and 600mm and a length of 235m each. The water is supplied into a discharge reservoir through a 6.7km long pipe of 600mm diameter.

The whole system was refurbished in 2001, when new pumps were installed. Due to the variable water demand, reduced after metering the consumers in the city, the well field is working at partial loads. This could be dangerous since it may determine a significant increase of the flow rate on the operational wells, which might cause their rapid deterioration.

In order to cope with this problem, several solutions may be adopted. One of them is based on orifice plates (diaphragms) mounted on pipes at some critical points. Another solution is based on pumps equipped with variable speed drive, operating at different duty points, in order to maintain the admissible variation of water level in each well.

The first solution has a big disadvantage in operation, related to the total operation costs, since all pumps are operating at 100% speed and are unable to ensure a different demand, or the maximum flow rate of the well field if the consuming pattern is changing. The second solution is more efficient in terms of operational costs and more versatile, because it adapts faster to different demands of the network. However, for different patterns, different pumping scheduling must be imposed.

2. Well field operation restrictions and optimization

The issue of optimizing the groundwater extraction network, including the pumping equipment, is currently addressed in many reports [1÷3], papers [4,5] and books [6,7]. Generally, the algorithm is based on several assumptions [8]. First of all, the optimum well flow rates has to be imposed and maintained during the operation, otherwise a rapid clogging of the wells will occur, leading in most cases to the destruction of them. Second, as few as possible pump types should be selected for maintenance reasons. And third, it must be considered that operation takes place sometimes at partial load, i.e. at flow rates which are lower than those for which the entire well field was designed. The operation of a water well field has to be realized at partial loads either due to a lower consumption of water, or due to revisions or damaged equipment replacement, meaning that some of the pumps are off. In the latter case, at least intuitively, it is obvious that all duty points of the pumps in operation migrate to the right, at higher flow rates.

To solve the first two goals, several simulations have been previously performed for the Mandruloc groundwater well field [8,9], using an optimization software built in Fortran. The computations gave a proper selection of the working pumps and an appropriate selection of minor head losses (orifice plates), to restrict the flow from surpassing the optimum flow rate for each well.

The problem, however, is the third goal: the analysis of the partial load operation at the design stage, in connection with the optimal equipment. In this paper, we address this goal by using variable speed driven pumps for the studied Mandruloc groundwater well field.

3. Numerical model

We built in EPANET a numerical model of the Mandruloc groundwater well field, based on the system geometrical description made in Section 1. The general scheme of that well field is presented in Fig. 1. The well field includes a number of 13 wells (labelled from W1 to W13, in Fig. 1), equipped with only two types of submersible pumps, namely: Wilo-K 84-2 (wells W4, W8÷W11, W13) and Wilo-EMU K 85-2 (wells W1÷W3, W5÷W7, W12).

The elevations of the nodes match the existing configuration, except for the nodes representing wells, where the elevations match the predicted hydrodynamic level of water in the well working at optimal flow rate. Wells are simulated as emitters with a very high value of the emitter coefficient (100000), so that the flow rate trough the emitter can adjust freely with respect to the value of the pressure at the emitter. In our case, due to the reduced pressure on the suction side of the pumps, the flow at the emitter is negative, i.e. water enters the pipe system. After each pump, a check valve was included in the vertical discharge pipe.

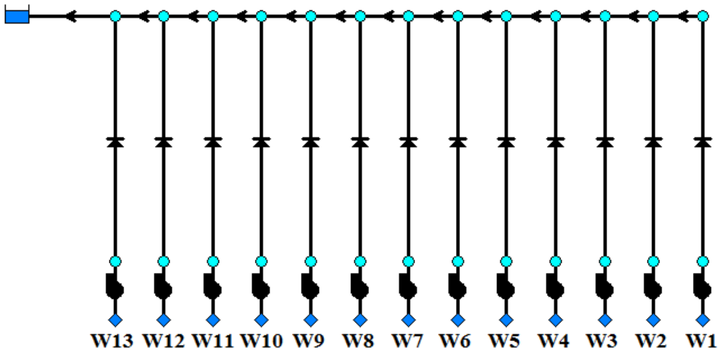


Fig. 1. General scheme of the well field.

The numerical model described before enables detailed simulation of the operation of the entire hydraulic system. For numerical simulations, we used the real well field, rehabilitated and optimized according to the algorithm described in Cioc and Anton [6,8].

The optimum pumped flow rates for the wells W1÷W13 are dictated by hydro geological studies, as in Fig. 2.

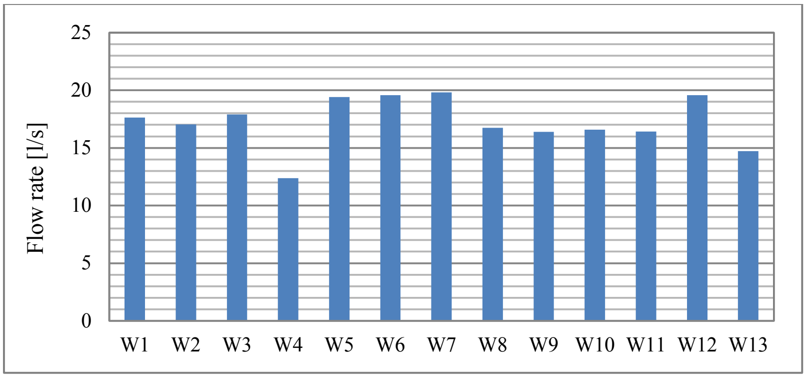


Fig. 2. The optimum flow rates (in l/s) for each well, labelled from W1 to W13.

4. Solutions for the Mandruloc well field operating at partial load

In order to simulate the operation of the studied well field at partial load, we decided to stop successive wells, placed at different positions within the field. Thus, starting from the reference variant (denoted further as v1), where all 13 pumps are working with optimum flow rates, and using a heuristic procedure, two cases of operation were analyzed:

- stopping 3 pumps in a package – variants v2 (pumps of wells W1÷W3 off), v3 (pumps of wells W4÷W6 off), v4 (pumps of wells W7÷W9 off) and v5 (pumps of wells W10÷W12 off);
- stopping 6 pumps in a package – variants v6 (pumps of wells W1÷W6 off) and v7 (pumps of wells W7÷W12 off).

Firstly, the working pumps speed was kept constant (equal to the nominal speed). The results show that, without exception, the optimum flow rate values (from Fig. 2) are exceeded by at least 10%, reaching up to 33%. The examples represented in Fig. 3 are the two extremes of the overtaking flow rates, corresponding to the variants v2 and v7. The flow rate distributions for those two variants are presented in Fig. 4 and Fig. 5.

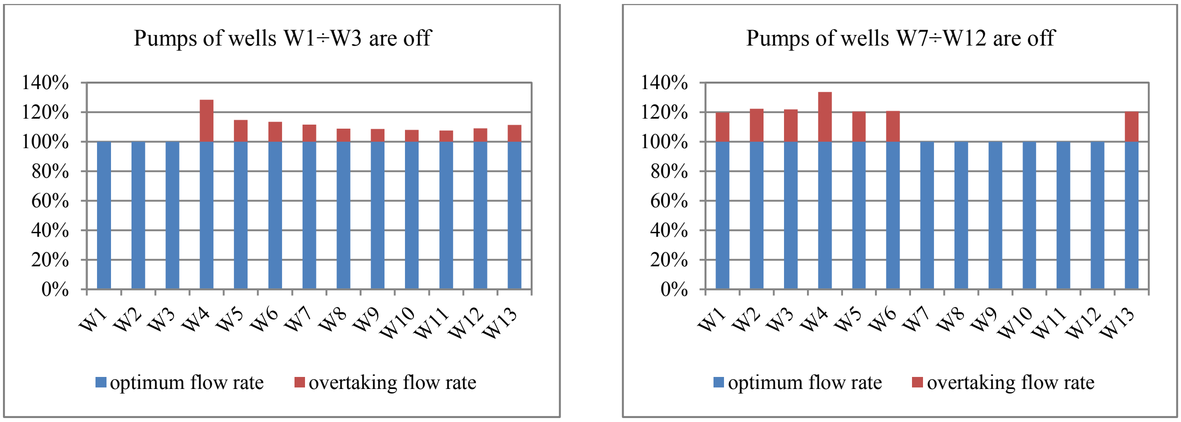


Fig. 3. Analyzed cases of operation with working pumps at nominal speed: variant v2 (left image); variant v7 (right image).

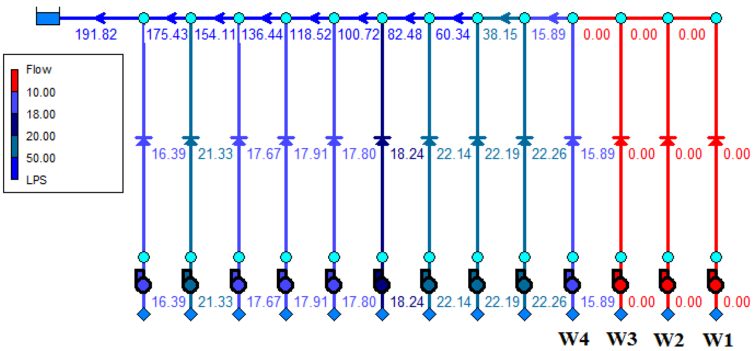


Fig. 4. Flow rate distribution (in l/s) for the variant v2, where pumps of wells W1÷W3 are off, and the remaining pumps work at nominal speed.

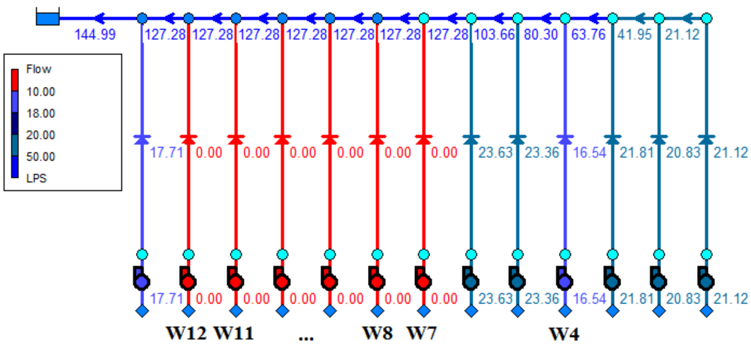


Fig. 5. Flow rate distribution (in l/s) for the variant v7, where pumps of wells W7÷W12 are off, and the remaining pumps work at nominal speed.

As expected, not all wells have similar behaviours, especially in a rehabilitated field. In the studied case, it is obvious that the well labelled as W4 has always an overtaking flow rate bigger that the others, in percentages (see

Fig. 3), although it's contribution to the total flow is the smallest of all (see Fig. 4 and Fig. 5). That is the reason why that well has to be kept as a "spare" well, and must be put last in operation.

Our proposal is to create a well field matrix, where the reference column represents the optimum flow rates as in variant v1, and the other columns are the overtaking flow rates at partial load (e.g. variants v2÷v7). An example of such a type of matrix is illustrated in table 1, for the computations performed with the working pumps at nominal speed.

Table 1. Well field matrix for working pumps at nominal speed.

Pump Type	Well	Full load (%)	Partial load (%)					
		Reference **v1**	**v2**	**v3**	**v4**	**v5**	**v6**	**v7**
EMU K 85-2	W1	100	0	14.64	11.24	9.08	0	19.86
EMU K 85-2	W2	100	0	16.44	12.45	10.04	0	22.31
EMU K 85-2	W3	100	0	15.91	12.51	10.16	0	21.78
K 84-2	W4	100	28.35	0	19.79	15.91	0	33.60
EMU K 85-2	W5	100	14.68	0	11.13	9.07	0	20.35
EMU K 85-2	W6	100	13.39	0	11.29	9.15	0	20.75
EMU K 85-2	W7	100	11.65	11.55	0	9.23	23.31	0
K 84-2	W8	100	8.90	8.84	0	7.46	19.16	0
K 84-2	W9	100	8.67	8.61	0	7.88	18.80	0
K 84-2	W10	100	8.09	8.03	8.39	0	17.62	0
K 84-2	W11	100	7.61	7.55	7.86	0	16.69	0
EMU K 85-2	W12	100	9.05	8.95	9.36	0	19.43	0
K 84-2	W13	100	11.42	11.35	11.69	12.17	20.60	20.39

Such a matrix can prove useful in three important stances:

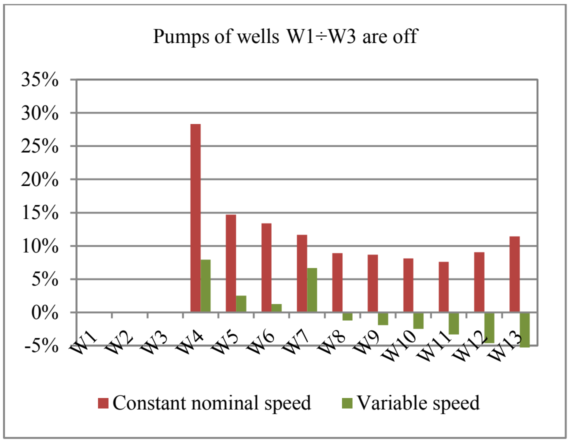
- it enables the evaluation of the energy loss when protecting the wells by throttling each vertical column till the flow reaches the optimum;
- it enables the establishment of a hierarchy among the wells and thus identifies the "spare" wells (or backup wells), as the wells where the supplementary head losses are the biggest;
- in case of a modern regulatory system based on variable speed drive, the matrix allows the identification of the best pumps for operation at partial loads, with the lowest energy consumption.

To avoid the overcharge of certain wells, a set of rule-based control statements were introduced in EPANET, to ensure the variation of pumps' speed, in order to maintain the admissible variation of water level in each well. The command of the controls is given by the pressure at the discharge node of each pump, that pressure being maintained within 1 m of a water column variation with respect to the pressure calculated in variant v1. We allowed a rotational speed variation, for each pump, only between 100% and 95% of the nominal speed, in discrete steps of 2.5%. A total of 52 rule-based controls were implemented for all 13 pumps (there are 2 decreasing speed steps and 2 increasing speed steps for each pump); e.g. the controls of the pump at well W4 are written as:

"*Rule 1* *if junction 4 pressure below 48, and pump W4 setting is 0.975, then pump W4 setting is 0.95*
Rule 2 *if junction 4 pressure below 48, and pump W4 setting is 1, then pump W4 setting is 0.975*
Rule 3 *if junction 4 pressure above 49, and pump W4 setting is 0.975, then pump W4 setting is 1*
Rule 4 *if junction 4 pressure above 49, and pump W4 setting is 0.95, then pump W4 setting is 0.975*"

For the variants v2 and v7, we present in Fig. 6 the comparison between the overtaking flow rate values of each well, obtained with working pumps at constant nominal speed versus working pumps at variable speed.

The proposed pumping control algorithm gives better results with respect to both the solution obtained with pumps speed kept at its nominal value, or to the former solution with orifice plates mounted on pipes [8].



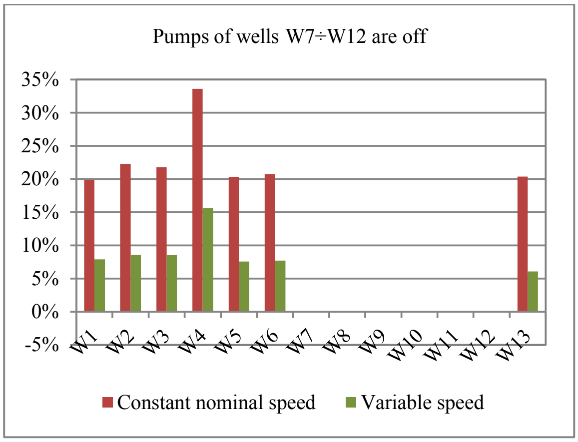


Fig. 6. Overtaking flow rate comparison between solutions with working pumps at nominal speed versus working pumps at variable speed: variant v2 (left image); variant v7 (right image).

5. Conclusions

Analyzing the results of the numerical simulations one can draw some conclusions:

Operation at partial loads is dangerous and determines a significant growth of the individual well flow, which might cause their rapid deterioration. A solution to reduce this effect is to consider, in the design phase, the hydraulic optimization of some cases of partial load flow rate. This analysis should be combined with a cost analysis to determine a suitable number of backup wells.

The obvious solution at hand now is to have all the pumps equipped with variable speed drives. This solution will replace in time the actual common system that controls the flow at each well, by introducing additional hydraulic resistance.

Through simulation scenarios, using appropriate models that minimize operating costs on one hand, and decrease the degree of empiricism in the decision process on the other, the overall design and operation of a well field can be optimized. In this process the well field matrix can be a useful tool.

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